Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

84C

CROP INJURY BY BORAX IN FERTILIZERS

MAR - - 1920

OSWALD SCHREINER, B. E. BROWN
AND J. J. SKINNER
Soil-Fertility Investigations
and
M. SHAPOVALOV
Cotton, Truck, and Forage Crop Disease Investigations

UNITED STATES DEPARTMENT OF AGRICULTURE
DEPARTMENT CIRCULAR 84

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. February, 1920

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1920

CROP INJURY BY BORAX IN FERTILIZERS.

CONTENTS.

	Page.
Earlier experiments and observations	3
Investigations by the Department of Agriculture	3
Effect of borax in potato fertilizers	12
Report on the condition of potato fields in Maine	13
Report on field experiments with potato fertilizers containing borax	20
Effect of borax in cotton fertilizers	24
Report on the condition of cotton fields in South Carolina	25
Report on field experiments with cotton fertilizers containing borax	27
Greenhouse experiments in pots on the toxicity of borax	32

EARLIER EXPERIMENTS AND OBSERVATIONS.

IN 1917 some injurious effects of borax in corn fertilizers were noted in Indiana, and Prof. S. D. Conner, of the Indiana Agricultural Experiment Station, published in September, 1918, a report of his findings in this matter, which attracted considerable attention, owing to the fact that such very small amounts of borax produced poisonous effects on corn. This seems to be the first recorded field observation of the effect of borax and its occurrence in fertilizer practice.

The work of the New Jersey Agricultural Experiment Station a few years ago was confined to pot tests and is rather inconclusive, while the work of Cook, of the United States Department of Agriculture, concerned itself chiefly with the action of borax in manure and is therefore not directly applicable to modern commercial fertilizer practice; neither are the experiments and observations of several European workers. In all these experiments the borax was greatly diffused by broadcasting, spreading, and mixing, whereas modern practice with commercial fertilizers involves drilling in, or, at the most, only limited spreading, which practice brings the fertilizer in closer contact with and in greater concentration near the seed. This method has shown itself successful in practice where fertilizers are normal in composition, but when these contain injurious elements the danger is much accentuated, as is shown with respect to the presence of borax in the results of Conner and as will become apparent in the reports of field observations in the following pages.

INVESTIGATIONS BY THE DEPARTMENT OF AGRICULTURE.

Conner's conclusion was essentially that 100 pounds per acre of a fertilizer containing 2 per cent of borax caused damage to the corn plant.

To many the statement that this small amount of borax[1] was harmful to germination and produced such marked physiological effects as complete bleaching of the leaves of plants, even though used in the drill, seemed incredible. Accordingly, it was decided to undertake preliminary experiments along this line during the season of 1919, and for this purpose 1 ton of potash salt manufactured from the deposits of Searles Lake, Calif., was obtained. This potash salt, which on analysis proved to contain 6.25 per cent of borax ($Na_2B_4O_7$), was used in complete fertilizers having 2 to 8 per cent of potash and was compared with potash from other sources. The experiments were carried out in cooperation with farmers in the States of Maine, New York, New Jersey, Virginia, North Carolina, South Carolina, and Georgia, with potatoes in the Northern States and as far south as North Carolina and with cotton in the Southern States.

While these experiments were in progress, reports and appeals reached the Department of Agriculture from farmers and from fertilizer mixers and distributors which indicated that in certain sections thousands of acres of crops on which potash fertilizers had been used presented an unusual appearance calling for immediate investigation. Several investigators were sent to the regions more seriously affected in Maine to study the effect of potato fertilizers and to North Carolina and South Carolina to study the effect of cotton fertilizers. Practically all the evidence collected points to the use in fertilizers of potash salts containing borax in what proved in practice to be excessive quantities. The higher the potash content of such mixed fertilizers the higher was also the borax content and the greater the damage to the crop. This damage was greatest when the fertilizer had been drilled in with the seed and was more severe where the soil and climatic conditions were such as to leave the fertilizer and seed, or the sprouting seed, too long in contact with the borax-containing salts. The greatest damage was done to germination, which was either entirely prevented or much delayed, sometimes many weeks. This showed itself in many missing hills, producing a poor stand and consequently a reduced yield.

In the case of potato fields thus affected practically all stages from germination to apparently normal plants were found. The affected plants showed certain characteristics which can not be confused with any other disease and which are fully described in this circular. The least striking effect noticed is a foliage of somewhat lighter green than normal, while the more affected plants show leaves slightly rimmed, like a pond-lily leaf, this rim being bleached white or yellowish, so that the effect of borax-containing fertilizers has been rather aptly called ''gilt-edged.'' In more extreme cases the leaves of potato or cotton plants may be completely bleached, but they are rarely found in the field, as such badly affected plants die soon after emerging from the soil. With corn and wheat this bleached leaf is the more usual characteristic.

---

[1] Wherever the amount of borax is mentioned in this circular, anhydrous borax is to be understood.

It is not thought likely that damage of a permanent character has resulted this year on the fields subjected to this borax trouble. This is indicated by the fact that rainfall immediately following the application of the fertilizer, a moister condition of the soil when applied, a slightly reduced quantity used, owing to the improper regulation of the drill, or a better distribution in the soil, especially when broadcasted, all tend toward a marked reduction, even to the vanishing point, in the harmful effect of the borax. There may be a cumulative effect, but upon this question there is no evidence. Should borax continue to be used as an ingredient of fertilizer materials, even in moderate quantities, it will become an important duty of those responsible for fertilizer experimentation to test this possible cumulative action by a well-planned long-term fertilizer experiment. This should be done on many soil types in many localities, but can be carried out safely only on land under the control of the Federal Government or the State agricultural experiment stations.

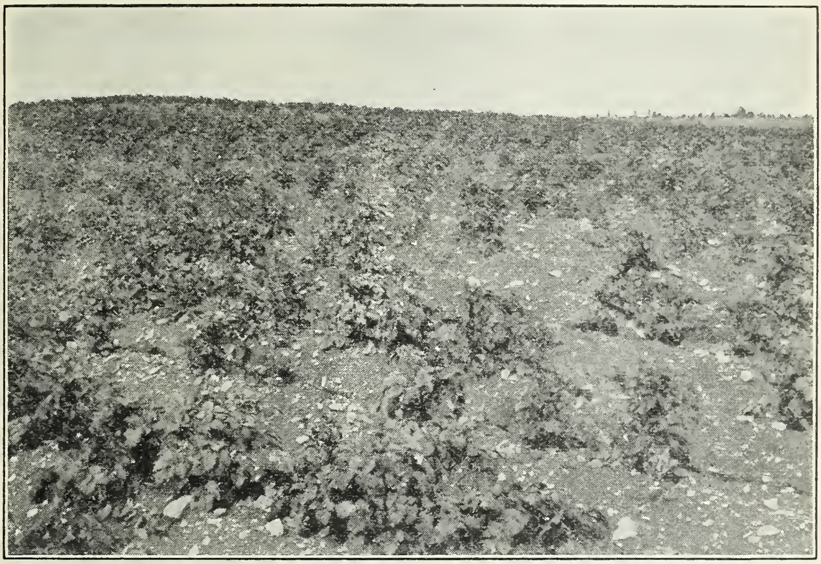


Fig. 1.—Field of potatoes showing the injury caused by the use of 1 ton of 4–8–6 fertilizer containing 46 pounds of borax per acre. Note the many missing hills and small plants. Photographed July 28, 1919, when normal fields were in blossom, as shown in figure 13.

Analyses showed that the borax content in many commercial mixtures found on affected farms was rather high, varying from 0.73 to 2.3 per cent. This quantity, when used in ton lots, as is common in the potato regions of Maine, means an application of 14.6 to 46 pounds of borax to the acre. This in a 4 to 6 per cent potash fertilizer indicates an abnormally high borax content in the original potash salt used to make these mixtures. An examination of the potash salts occurring in commerce showed that some contained as much as 12, 20, and even 30 per cent of borax.

In the experiments of the Department of Agriculture with the 6.25 per cent borax-containing potash salt, using this in 2 to 8 per cent potash mixtures, no such serious injury has resulted as occurred in commercial fields, but even here the yields were materially affected. These yields for the different soil types and locations for both potatoes and cotton are presented in the tables which follow.

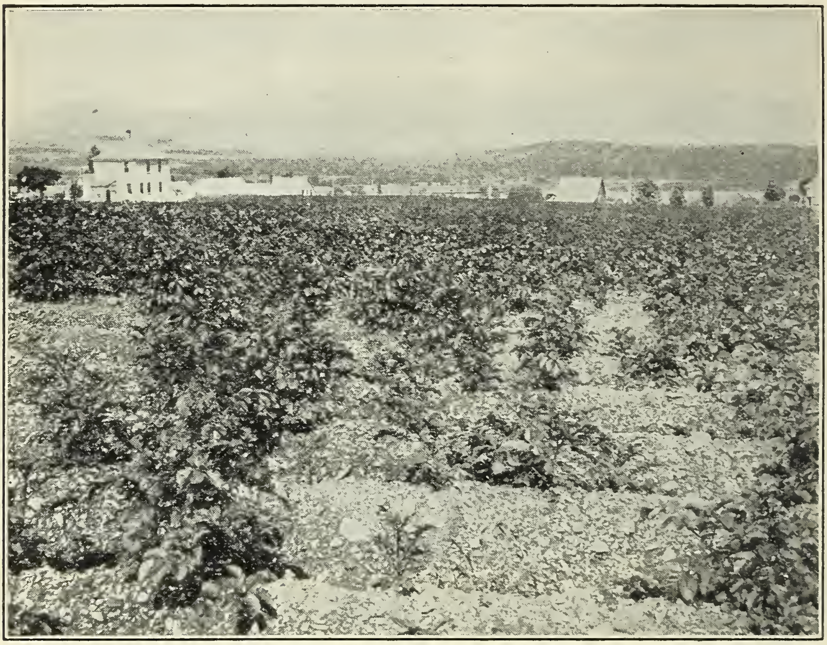


FIG. 2.—Potato field showing injury from the use of a commercial 3-6-6 fertilizer. Note all stages of injury, from apparently missing hills to small stunted plants; also some that appear almost normal. In the background a 4-8-4 fertilizer was used, applied at the same rate, showing no injury.

While it has been pointed out in the foregoing paragraphs that the salt deposit of Searles Lake, Calif., which forms an important American source of potash, contains borax, this is not the only fertilizer material in which borax occurs. Borax also is found in the high potash nitrate shipped from Chile and may occur in smaller quantities in nitrate of soda, sometimes in appreciable amounts. Boron is a very widely distributed element in the earth's crust and appears in appreciable quantities in certain waters and springs and in deposits formed by the evaporation of these waters. Searles Lake is such an accumulation of evaporated salts, as are also the deposits of niter in Chile. The European salt deposits have been laid down in a different manner, in stages, as it were, rock salt here, gypsum there, and potash salts in another layer or horizon, so that borax also would appear only in definite portions of the deposits rather than diffused throughout the salt mass, as in the case of the Searles Lake or the Chilean deposits. It is, however, perfectly feasible in the process of manufacture to lower the borax content to a very small quantity, and this has already been accomplished by the companies operating on the Searles Lake deposit by crystallizing, centrifuging, and washing, so that the same company that during the haste induced by the war turned out a product running 10 per cent of borax, which in unguarded factory runs rose sometimes to 20 per cent and higher, is now, under more scientific control, turning out potash salts with less than one-half of 1 per cent of borax. It should prove feasible to accomplish the same result in the manufacture of high potash nitrate and even of sodium nitrate. Should borax appear in other salts also, from Europe or elsewhere, no serious difficulties should present themselves to the manufacturer in reducing its content to the limits of safety in agricultural practice. This means, of course, careful chemical control. The fertilizer industry is a branch of the larger chemical industry which has developed only through proper scientific control, and the haphazard methods of a few years ago are things of the past in view of the many new materials entering

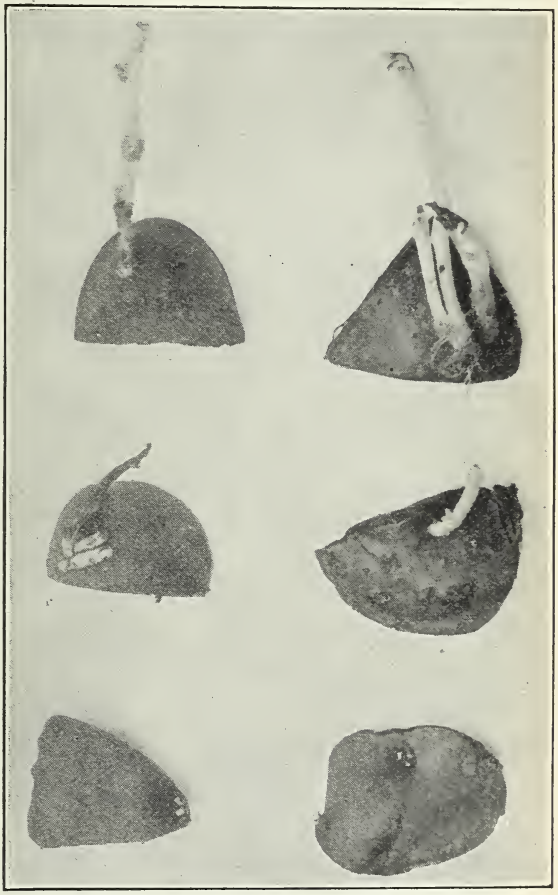


Fig. 3.—Potato seed pieces dug from apparently missing hills, showing various stages of borax injury. These seed pieces had been in the ground about 2½ months. Note various attempts at sprouting.

into fertilizer practice which require both chemical and plant physiological investigation.

In addition to the observations on commercial potato and cotton farms and the experiments of the Department of Agriculture in the field, greenhouse studies with pots to obtain some idea of the limits of toxicity of borax were inaugurated. A very considerable number of fertilizer mixtures were used, with wheat and cotton as the plant indicators of toxicity and with a much wider range of borax content than was feasible in the field experiments. This indicated for wheat plants a toxic limit of 2 to 3 pounds of borax per acre, while with cotton this toxic limit appeared to be higher, between 8 and 9 pounds per acre. The reactions were in all cases decisive and left no doubt as to the poisonous action of the borax on the plants. These quantities are small compared to those of other poisons, such as arsenic,

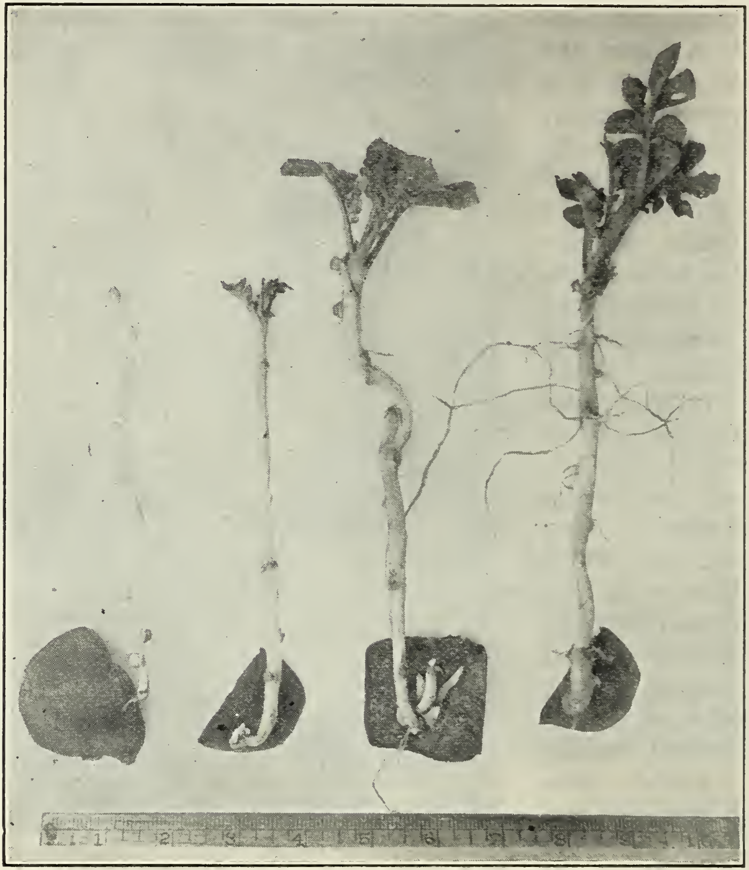


Fig. 4.—Further stages of borax injury. These potato plants were just emerging from the soil after 2½ months of struggling for existence. Note the absence of normal roots. Normally these plants with a proper fertilizer would have had the appearance at this time of year of those shown in figure 13 or 15.

mercury, and copper salts, which, though considered very toxic to plant life, can nevertheless be used to the extent of 50 pounds or more per acre without serious damage. From 10 to 20 pounds of copper sulphate have been applied to each tree in certain orchard work, and

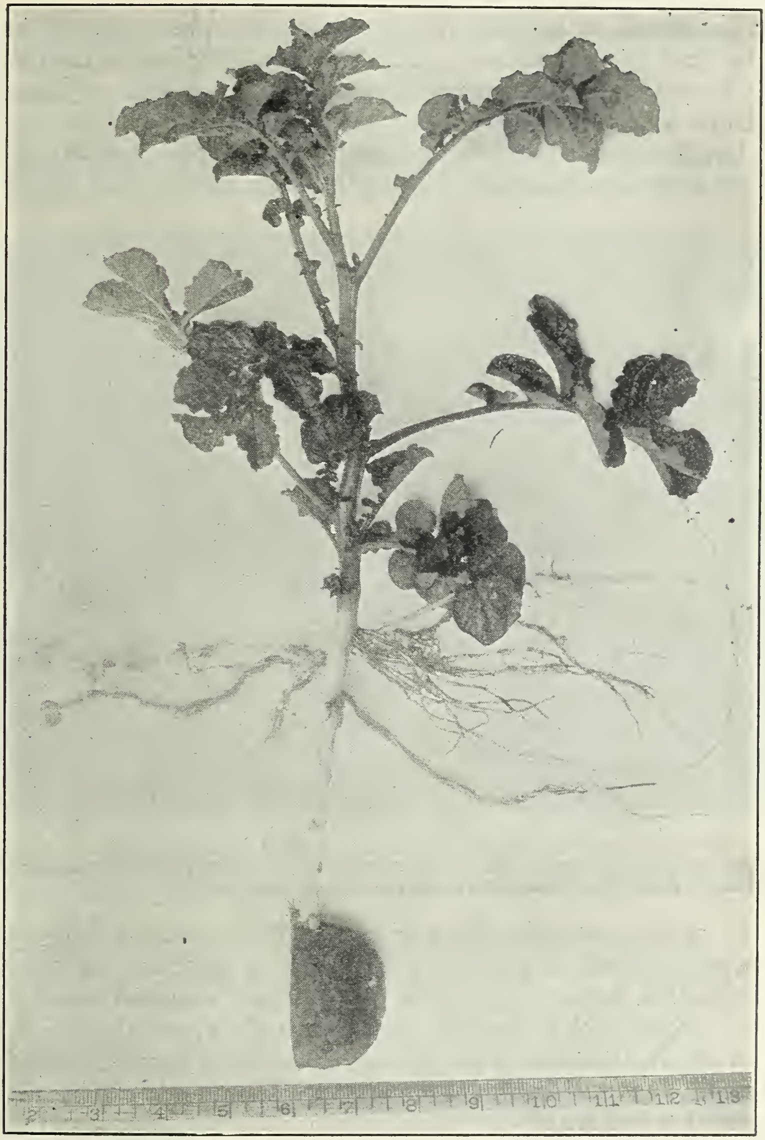


Fig. 5.—A borax-injured potato plant which has survived but is small and weak. Note, again, the absence of normal roots near the seed piece and the later development of roots higher up, above the fertilizer zone, near the surface of the ground. Photographed at the end of July. Little can be expected of this plant in the way of profitable tuber formation. Plants of this type were exceedingly numerous.

mercuric bichlorid, or corrosive sublimate, is used by potato growers in a 0.1 per cent solution as a bath for sterilizing potato tubers and is considered perfectly safe in practice.

It is difficult to explain the extremely poisonous action of borax except that it is specific to the element boron contained in the borax. It is known to be a strong antiseptic, so that a partial explanation might be sought in the sterilizing action which it may have on the soil, but the specific physiological reactions of the plant would suggest a more intimate connection with the growing functions of the plant itself. A suggestion is perhaps to be found in some work done many years ago in which it was shown definitely by chemical and physical methods that borax was capable of forming a chemical union with sugar alcohols, such as mannite, erythrite, arabite, and glycerin, upon which combination one of the present methods for determining borax is based. It is well known that sugars are liberated in the process of germination and are of service in the translocation of starch and other carbohydrate material in the plant, and it may be that borax interferes with this highly important function, disturbing thereby very seriously the process of germination and growth. It may also prove to be antizymotic; that is, detrimental to the enzym action which accompanies and is vital to the processes of germination and growth. Whatever its mode of action, the fact that it seriously interferes with germination and growth seems now well established, and since borax

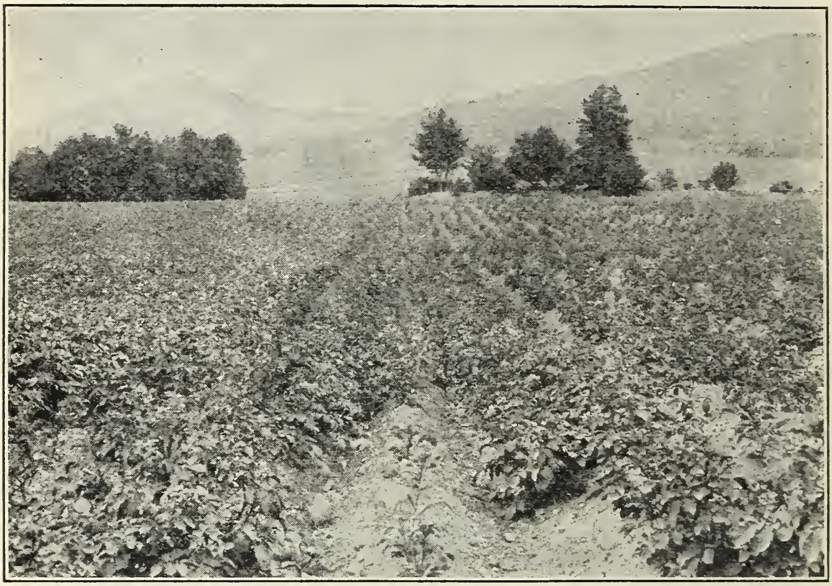


FIG. 6.—A comparison between 4-8-4 and 4-8-6 fertilizers. Note the better stand of the 4 per cent potash fertilizer, on the left, as compared with the 6 per cent fertilizer, on the right, which shows a poorer stand with smaller plants, the field presenting an open and broken appearance.

has occurred in fertilizers this poisonous action has decided practical significance. The facts as far as they have been ascertained are presented for the consideration of the farmer, the fertilizer mixer, and the manufacturer of fertilizer materials likely to contain borax, so that the borax may be (1) as far as is practicable eliminated in the process of manufacture, (2) reduced in the process of mixing fertilizers by the judicious selection of materials to a content safe for ordinary use with the methods of application and rates of fertilizers per acre commonly employed in connection with those crops requiring large applications, and so that (3) with this borax content known the farmer can use his judgment, based on his fertilizer practice, as to the best method of application and the proper quantity to mix in order that the amount of borax per acre may be kept within safe limits. When so restricted no serious results can occur, nor should the presence of such prescribed amounts of borax in fertilizers prove prejudicial to their sale or use.

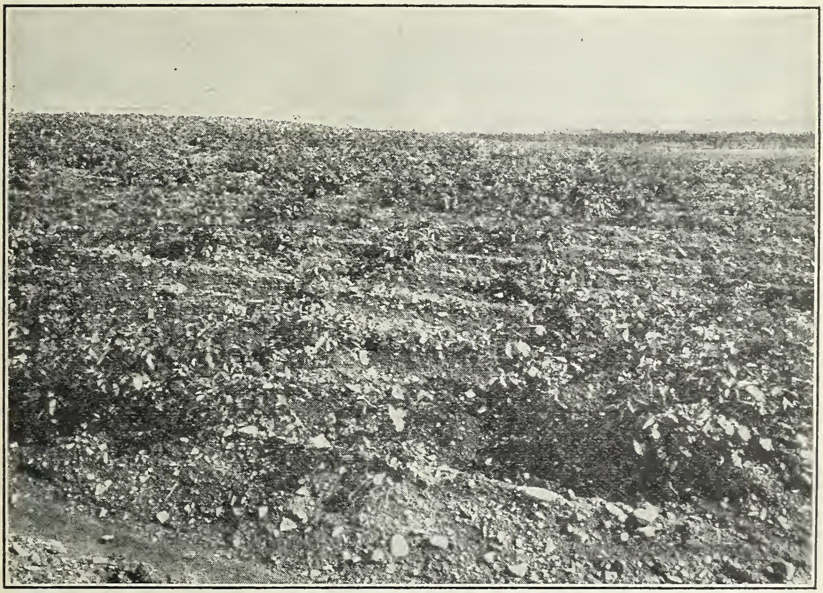


Fig. 7.—Potato field showing the injury caused by the use of 1 ton of 4–8–6 fertilizer per acre. A sample of 4–8–4 fertilizer used on the same farm analyzed 16 pounds of borax per ton. The stand with the 4–8–4 goods was noticeably better.

The main facts ascertained by these investigations are reported in the following pages, and photographs are reproduced to illustrate more clearly the character and extent of the injury which was occasioned by the use of borax-containing fertilizers.

EFFECT OF BORAX IN POTATO FERTILIZERS.

When it became apparent in 1919 that the potato-producing districts of Maine were suffering from an unusual condition it was deemed wise to conduct an investigational survey of the crop injury cooperatively by the Offices of Soil-Fertility Investigations and Cotton, Truck, and Forage Crop Disease Investigations, so as to have not only the soil-fertility and fertilizer aspects of the case from a plant-nutrition viewpoint investigated, but also a thorough control on the pathological aspects in order not to be misled by the influence of well-known potato diseases. Mr. B. E. Brown and Mr. M. Shapovalov, of these respective offices, conducted the survey in Maine from July 28 to August 8, 1919. Somewhat later Dr. Oswald Schreiner inspected this same region and also continued the investigations into Vermont and northern New York, but he found in these regions no injury comparable with that observed by Brown and Shapovalov in Maine as due to borax. They investigated about 60 farms in the townships of Presque Isle, Mapleton, Mars Hill, Fort Fairfield, Caribou, Limestone, Van Buren, St. Agatha, and Fort Kent, as well as in the vicinity of Houlton, Dyer Brook, and Orono, and took more than 60 photographs of fields and individual plants, to show the effect of the fertilizer injury. Some of these are reproduced in this circular. Samples of fertilizers secured wherever possible were analyzed for borax in the laboratory by Mr. R. B. Deemer.

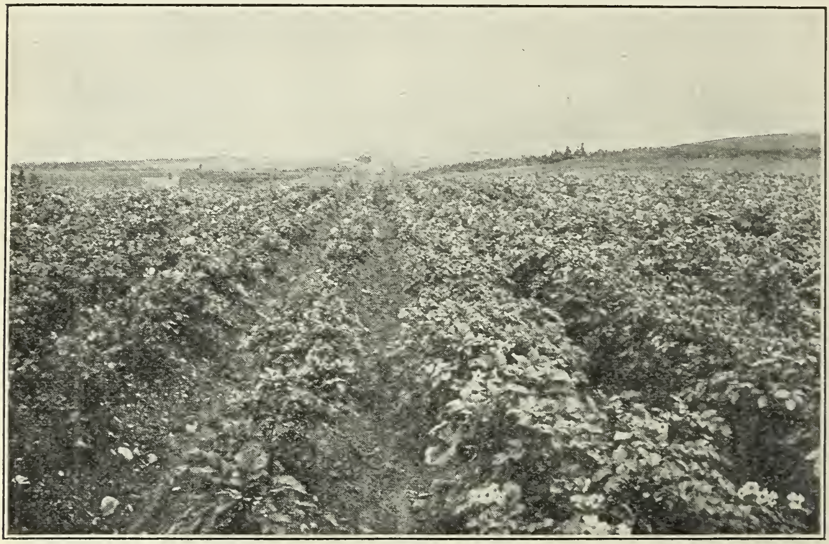


FIG. 8.—Comparison between a 5-10-0 row of potatoes, on the right, and a 4-8-4 row, on the left. With a normal fertilizer of 4-8-4 composition this would have been superior to 5-10-0.

REPORT ON THE CONDITION OF POTATO FIELDS IN MAINE.

General conditions of health.—The potato fields in the sections surveyed in Maine up to and including the time when this investigation was made showed a remarkably small injury from parasitic diseases. An insignificant amount of early blight (*Macrosporium solani*) was found scattered on the lower leaves of potato plants, but the most severe malady, late-blight (*Phytophthora infestans*), was practically absent. A period of continued dry weather in June and July was unfavorable to an early start of this disease. Wilt (*Verticillium albo-atrum*) was present in 1919, though found only in a few large commercial plantings, where it ranged from 5 to 15 per cent in different sections of the fields. A small amount of it was observed also on experimental plats at Presque Isle. Occasional black-leg plants were observed in different fields, but only in one large field of those inspected was the amount as high as 5 per cent. Underground stem lesions of the Rhizoctonia type were, as usual, quite common, and outside of wilt this seemed to be the most conspicuous manifestation of fungous activities in the Maine potato fields.

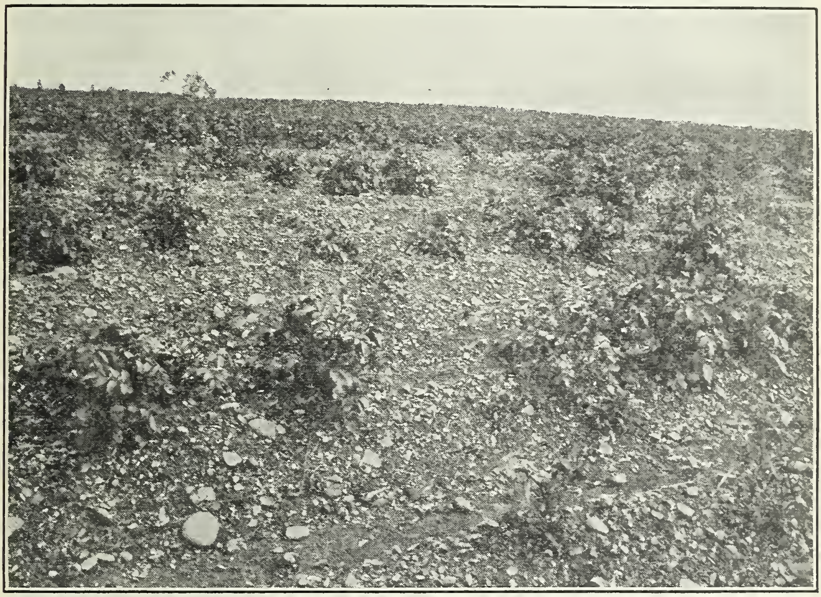


FIG. 9.—Potato field showing injury from the use of 1,800 pounds per acre of a 3–6–6 fertilizer carrying 33 pounds of borax per ton. The better field in the background was fertilized with a no-potash fertilizer (4–9–0).

Of the so-called physiological diseases, there was about the usual amount of mosaic, mainly in the Green Mountain and Bliss Triumph varieties. While in some fields it ran as low as 15 to 20 per cent, in others, where evidently no attention was paid to seed selection, it reached 90 or practically 100 per cent. However as a rule, the stage was slight to medium, and only in exceptional cases on a small number of plants was the curly-dwarf stage observed. A disease of Irish Cobblers most closely resembling mosaic (and in all probability identical with it) was noted in a few instances, and in one case it was associated with streak. Neither streak alone, not accompanied by mosaic, nor curly dwarf as a disease distinct from the late stage of mosaic, was noted in commercial fields that came under observation. Leaf-roll in many fields was either absent or slight, though a certain amount of it could be found scattered here and there on the Irish Cobbler and even less on the Green Mountain variety. A pronounced and quite severe outbreak of this trouble was observed only in one large commercial field. It also was quite manifest, although not so severe, on experimental plats at Presque Isle. The breaking down of the potato plants, now well known as caused by "potash hunger" or "malnutrition trouble," began to appear in some earlier planted fields where a fertilizer containing no potash was used.

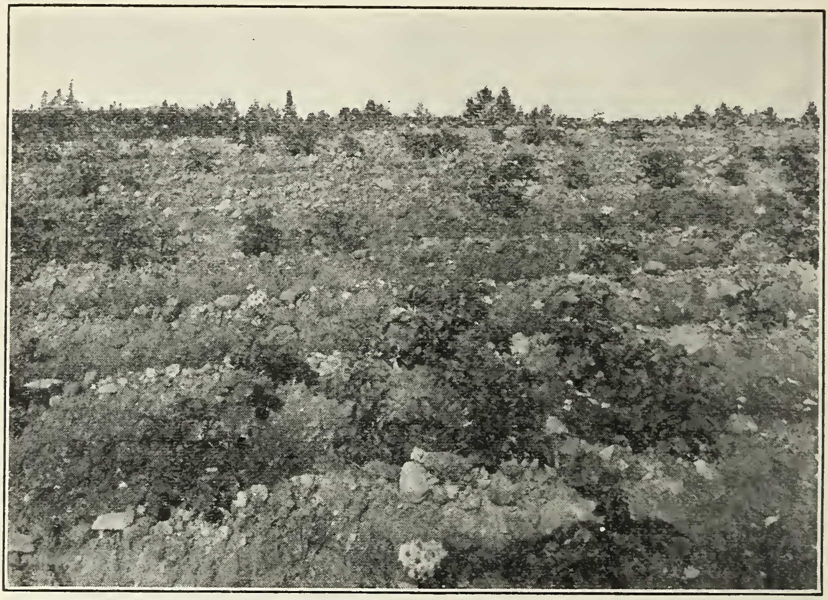


Fig. 10.—Potato field showing one of the most severe cases of injury observed. This was located on a knoll and the severity of the injury is believed to be due to the exceptional dryness of this soil. The condition of the plants was usually better in the lower lying areas of a field.

Conditions in Aroostook County.—Notwithstanding the comparative freedom from disease and aside from any losses that may be due to "potash hunger," the potato crop on certain farms in northern Maine threatened to be almost a complete failure, as shown in figure 1. Various growers stated that they did not expect more than one-third or one-half of their normal crop. The fields involved presented a

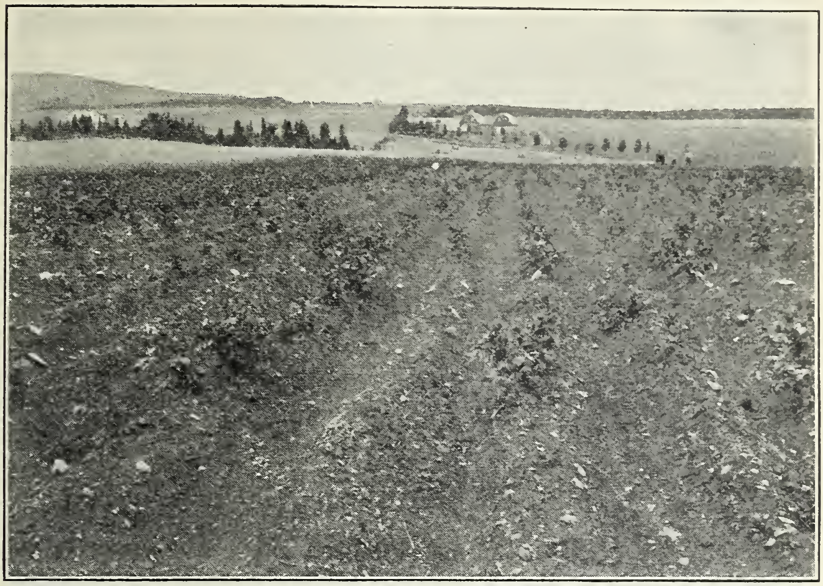


Fig. 11.—Potato field showing the injury caused by the use of 1 ton to the acre of 3–6–6 fertilizer containing 31 pounds of borax. At the edge of this field, to the left, note the much better stand where only one-half ton of this fertilizer was applied.

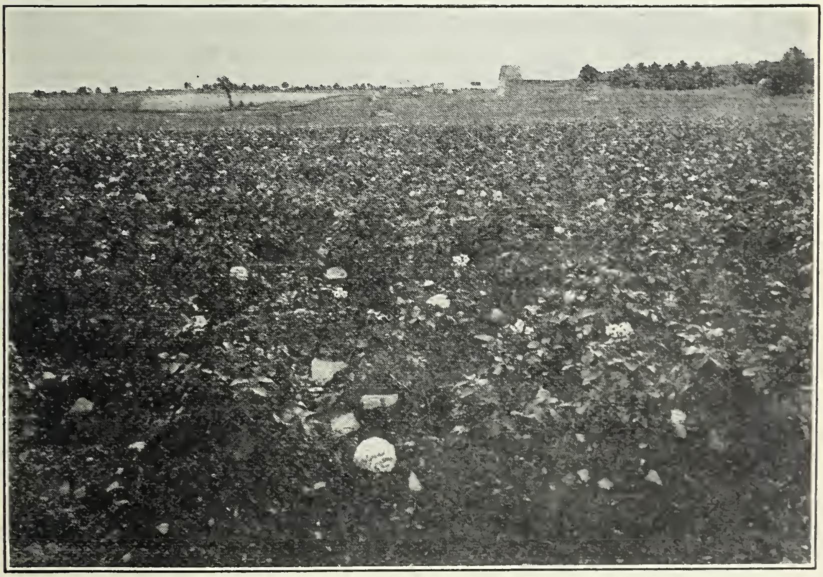


Fig. 12.—Field of potatoes showing an abnormal condition, to which 1 ton of a 4–8–6 fertilizer containing 23 pounds of borax was applied. (Photographed on the same farm shown in figure 13.)

striking and characteristic appearance. Many hills were missing, some plants just showing above the ground. Most of them were small and undersized, and only comparatively few approached the normal size, though still distinctly below the standard, as shown in figure 2. The plants in these affected fields possessed peculiarly characteristic features which exclude any possibility of confusing this trouble with any known disease. These features became obscure in larger plants, i. e., those which gradually overcame the trouble, but were quite pronounced in the smaller plants, and especially in those which were just coming up at the time of inspection. The stalks usually were not as thick as those in normal plants and often decidedly spindly; leaves small, leaflets narrowed, light in color, either entirely bleached (particularly when young) or with etiolated, yellow margins. This bleached effect and the small size of the plants were the most pronounced pathological symptoms in the foliage. There was no difficulty in distinguishing this trouble from leaf-roll or mosaic, and there were many fields where neither of these diseases was present where plants suffered severely in the manner just described. The underground portions of the affected plants presented their own striking characteristics. The lower roots,

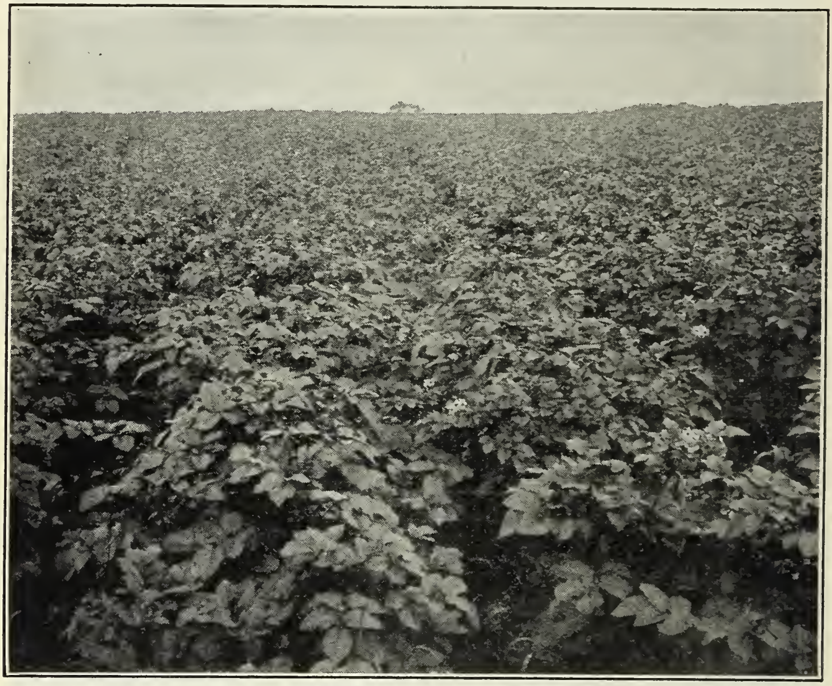


FIG. 13.—The normal condition of Aroostook County potato fields at blossoming time. Photographed at the same time as the other illustrations in this series. An application of 1 ton per acre of a normal 4–8–6 fertilizer had been made.

immediately above the seed piece, were frequently absent or had a stubby appearance, with brown, dead tips. Some seed pieces, however, remained in the soil, firm and sound, with eyes sprouted but unable to make further progress, as is well illustrated in figure 3. Frequently sprouts were injured and side shoots were produced, as shown in figure 4. Seed pieces often lay in direct contact with the fertilizer, thus being exposed to immediate injury during the germination and early growth period from any harmful element that might be present in the mixture. When plants had enough power to push through, another set of roots was formed close to the surface of the ground. (Fig. 5.) The undersized plants always had a very poor set of roots or none at all.

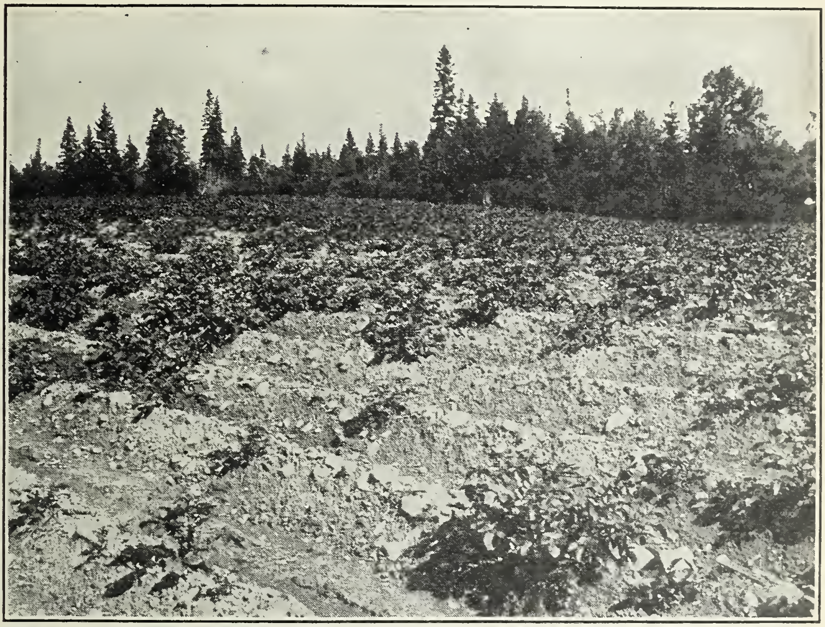


FIG. 14.—Potato field showing injury from the use of a commercial 4–8–4 fertilizer. Compare with figure 15.

In view of the number of abnormal fields it was considered essential to interview the farmers in order to find out just what had been done regarding the use of fertilizers; also to interview farmers whose potato fields presented a normal appearance. As a result of these inquiries it was ascertained that the above trouble was always associated with the use of certain brands of complete fertilizers. It was found that 6 per cent potash goods of such brands had caused considerably more injury than 4 per cent potash goods (figs. 6 and 7); that the results from no-potash goods looked better than where 4 per cent potash goods were used (fig. 8) and much better than where 6 per cent potash goods were used (fig. 9); that no fertilizer, in general, produced potato plants superior to those where 6 per cent potash goods were used, and while a great many "skips" occurred where the 4 and 6 per cent potash goods were used there were very few misses when no fertilizer was used; that a much better recovery from the injury had taken place where 4 per cent potash goods had been used than with 6 per cent goods; that the use of different planters resulted in the same degree of injury; that different soil types showed very little difference in the extent of injury; that low spots, the soil of which apparently retained more moisture, showed less evidence of the injury than the knolls (fig. 10); that half quantities of the injurious fertilizer caused considerably less injury (fig. 11); and that other crop plants, such as beans and buckwheat, were affected. A number of farmers called attention to certain fields where they had used the brands of fertilizer causing the trouble and manure also had been applied, as well as to other fields where no manure was used. In their opinion the use of manure tended to reduce the injury.

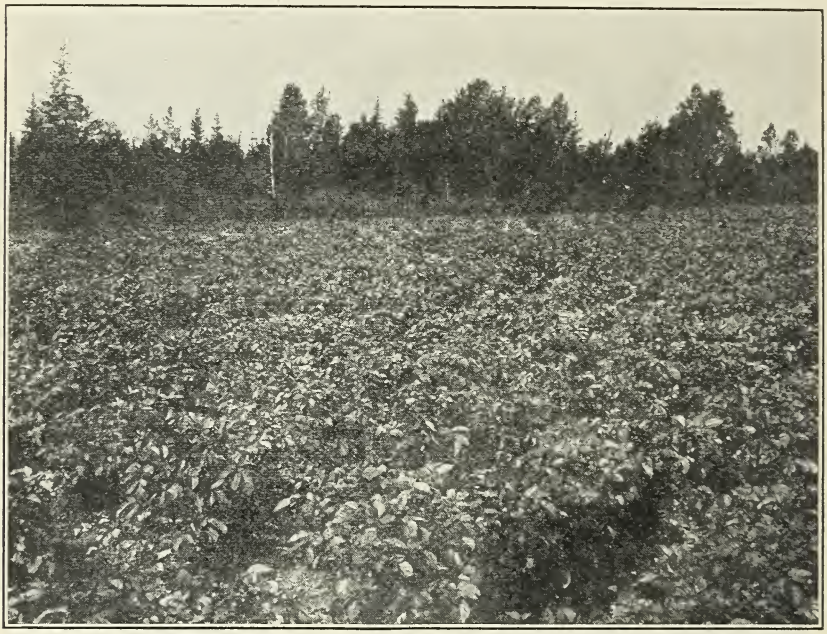


Fig. 15.—A good field of potatoes on which a home-mixed complete fertilizer was used. (Photographed on the same farm shown in figure 14.)

With regard to the response of different varieties to the present trouble it may be said that the Green Mountain variety withstood the injury better than the Irish Cobbler. The Bliss Triumph and "Hustler" varieties rank practically the same as the Irish Cobbler, and the Spaulding Rose variety, too, showed a considerable degree of susceptibility. Practically all the farmers interviewed said that considerable recovery followed rain, which was lacking during June and a part of July. Such recovery was more pronounced where 4 per cent potash goods were used than with 6 per cent goods.

Fortunately, for comparative purposes, many excellent fields of potatoes were found, none of which were produced with the brands of fertilizer causing the trouble. In many instances a farmer had used several kinds of fertilizers, and in such cases the fields presented an excellent demonstration of the effect of different potash fertilizers on the stand and growth of potatoes, as is well illustrated in figures 12 and 13; also in figures 14 and 15. Certain brands were injurious, while other brands with the same seed, soil, climatic conditions, and cultural care afforded fine results. What may prove, however, to be an unfortunate culmination of the trouble has to do with the set. A great many farmers were of the opinion that even where the plants apparently made considerable recovery, especially in the case of the 4 per cent goods, there were not many tubers underneath.

As a result of the investigation the conclusion was reached that the present injury to a number of potato fields in Aroostook County is due to certain fertilizers. A number of samples of these fertilizers were obtained, and an analysis of them will settle the point as to the amount of borax they contain, which compound, it is believed, is the cause of the injury. The analytical results are presented in Table I.

Conditions in Piscataquis County.—It should be stated at the outset that no farmer in Piscataquis County who had used 6 per cent potash goods was found. A number of fields in the vicinity of Dover and Foxcroft were observed where 4 per cent potash goods had been used and also where no-potash fertilizer had been employed. In the latter cases the no-potash goods, even at the time of the inspection, produced plants better than those fields where 4 per cent goods were applied, especially as regards stand and subsequent growth. In the cases where 4 per cent potash goods were used the fields had a number of misses, small plants, and other evidences indicative of the injury noted in fields where 4 per cent potash was used in Aroostook County. It can be stated, however, that only one fertilizer manufacturer's goods containing 4 per cent of potash which had caused harm was found, so the extent of the injury in this county did not seem proportionately as great as in Aroostook County.

A number of farmers stated that the potato fields looked much worse earlier in the season, but had improved considerably following rainfall. The observations made harmonize with this statement. If injury had resulted earlier in the season, considerable recovery must have ensued by the time of inspection.

TABLE I.—*Borax content of potato fertilizers collected in Maine.*[1]

Laboratory No.	Composition (per cent).[2]			Collected in—	Borax, $Na_2B_4O_7$ (per cent).
	NH_3.	P_2O_5.	K_2O.		
0224	4	8	4	Fort Fairfield	0.81
0225	4	8	4	Caribou	.76
0226	4	8	4	Presque Isle	1.21
0234	4	8	4	Houlton	.96
0237	4	8	4	.....do	.96
0227	4	8	6	Presque Isle	1.14
0228	3	6	6	Fort Fairfield	1.54
0229	3	6	6	Fort Kent	1.67
0230	4	8	6	Caribou	.78
0231	3	8	6	Mars Hill	.76
0232	4	8	6	Caribou	.73
0233	3	6	6	Van Buren	1.67
0235	4	8	6	Houlton (1918 sample)	.25
0236	3	6	6	Houlton	1.31
0238	4	8	6	Caribou	2.30

[1] Analyses made by R. B. Deemer of samples collected by Brown and Shapovalov.
[2] In all cases in this publication the order of the fertilizer constituents is ammonia, phosphoric acid, and potash.

REPORT ON FIELD EXPERIMENTS WITH POTATO FERTILIZERS CONTAINING BORAX.

The potash used in these cooperative fertilizer tests had been received from several American sources: Sulphate of potash prepared from Utah alunite, Nebraska Lake potash, and Searles Lake potash. The latter contained 6.25 per cent of borax ($Na_2B_4O_7$.) The tests were carried out cooperatively with farmers. These experiments were made on several different soil types in North Carolina, Virginia, New Jersey, New York, and Maine. The North Carolina station was under the supervision of Dr. J. J. Skinner and the four northern stations were under the supervision of Mr. B. E. Brown. The results obtained with potatoes at these various places are here reported. They are presented in tabular form, in which the yields of potatoes obtained with sulphate of potash, Nebraska potash, and Searles Lake potash are compared, the amount of potash in pounds applied per acre in each experiment and also the composition of the fertilizer used being specified. The potash was used in some places in 2, 4, 6, and 8 per cent fertilizer mixtures, and in others 3, 5, and 7 per cent. The remainder of the formula, the amount of phosphate and ammonia, differs in the different places according to the respective needs and practices of the region. The table also shows the amount of borax in pounds per acre which was applied along with the potash goods. The average yield of the fertilizer without potash, as determined in these experiments, is also given.

The method of distributing the fertilizer in these experiments was in nearly all cases more thorough than is customary with the farmer, so that it was mixed with the soil somewhat better than is usually done in practice. Owing possibly to this fact, there have not been noted any such extreme cases of injury in these experiments as have been observed in field practice, especially in Maine. The vines in all these experiments were in fair to good condition, the only abnormality noticed being a somewhat lighter foliage, and here and there perhaps a slight coloration of the edges of the leaves which suggested the borax injury.

In the yields of the potatoes, however, it can be seen that even this slight injury has done some damage to the crop. This is noticeably so on the light sandy soil of North Carolina and least noticeable on the heavier soil in Maine.

It will be noted (Table II, sec. A) that in North Carolina the 2 per cent potash fertilizer, carrying 5.9 pounds of borax, gave as good a yield as sulphate of potash, but that 4, 6, and 8 per cent potash fertilizers containing borax gave a markedly decreased yield as compared with sulphate of potash or, for that matter, the Nebraska potash, although it is considered preferable to use sulphate of potash as the best chemical basis for comparison.

With the 4 per cent sulphate of potash the yield was 273 bushels of potatoes, as compared with 133 bushels for the Searles Lake potash; for the 6 per cent potash goods it was 280 bushels for the sulphate of potash, and only 129 bushels for the Searles Lake potash; while with the 8 per cent potash it was 265 bushels for the sulphate of potash and only 120 bushels for the Searles Lake potash.

In Virginia, as shown in Table II, section B, the 3 per cent potash goods, carrying nearly 9 pounds of borax, also gave a decreased yield, the sulphate of potash producing 160 bushels per acre as compared with 118 bushels for the Searles Lake potash. This difference between the two potash goods is not as marked, however, in the higher amounts of potash in the fertilizer, so that perhaps this difference can not all be ascribed to the borax; but it is sufficiently large even in these higher amounts to indicate that it is not as good as the sulphate of potash, or, for that matter, the Nebraska potash.

TABLE II.—*Yields of potatoes grown on different soil types treated with fertilizers of stated composition, from several sources, applied at given rates per acre and containing varying percentages of borax; tests of 1919.*

SEC. A.—ON DUNBAR SANDY LOAM, NEW BERN, N. C.

[Fertilizer application, 1,800 pounds per acre; average control (5–7–0) yield, 152 bushels per acre; in cooperation with the North Carolina Agricultural Experiment Station.]

Items of comparison.	Sulphate of potash.	Nebraska potash.	Searles Lake potash.	Composition of fertilizer (per cent).		
				NH_3.	P_2O_5.	K_2O.
Potash (K_2O) per acre....pounds..	36.0	36.0	36.0	5	7	2
Borax ($Na_2B_4O_7$) per acre....do....	None.	None.	5.9			
Yield per acre....bushels..	234.7	211.3	238.7			
Potash (K_2O) per acre....pounds..	72.0	72.0	72.0	5	7	4
Borax ($Na_2B_4O_7$) per acre....do....	None.	None.	11.8			
Yield per acre....bushels..	273.3	222.0	133.3			
Potash (K_2O) per acre....pounds..	108.0	108.0	108.0	5	7	6
Borax ($Na_2B_4O_7$) per acre....do....	None.	None.	17.7			
Yield per acre....bushels..	280.0	213.3	128.7			
Potash (K_2O) per acre....pounds..	144.0	144.0	144.0	5	7	8
Borax ($Na_2B_4O_7$) per acre....do....	None.	None.	23.6			
Yield per acre....bushels..	265.3	216.0	120.0			

TABLE II.—*Yields of potatoes grown on different soil types treated with fertilizers of stated composition, from several sources, applied at given rates per acre and containing varying percentages of borax; tests of 1919*—Continued.

SEC. B.—ON NORFOLK SANDY LOAM, NORFOLK, VA.

[Fertilizer application, 1,800 pounds per acre; average control (7-7-0) yield, 153 bushels per acre; in cooperation with the Virginia Truck Experiment Station.]

Items of comparison.	Sulphate of potash.	Nebraska potash.	Searles Lake potash.	Composition of fertilizer (per cent).		
				NH_3.	P_2O_5.	K_2O.
Potash (K_2O) per acre.....pounds..	54.0	54.0	54.0	7	7	3
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	8.85			
Yield per acre.....bushels..	160.0	173.0	118.0			
Potash (K_2O) per acre.....pounds..	90.0	90.0	90.0	7	7	5
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	14.75			
Yield per acre.....bushels..	190.0	189.0	144.0			
Potash (K_2O) per acre.....pounds..	126.0	126.0	126.0	7	7	7
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	20.65			
Yield per acre.....bushels..	199.0	178.0	164.0			

SEC. C.—ON SASSAFRAS LOAM, HOLMDEL, N. J.

[Fertilizer application, 1,500 pounds per acre; average control (4-8-0) yield, 188 bushels per acre; in cooperation with the New Jersey Agricultural Experiment Station.]

Potash (K_2O) per acre.....pounds..	45.0	45.0	45.0	4	8	3
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	7.5			
Yield per acre.....bushels..	257.0	264.0	226.0			
Potash (K_2O) per acre.....pounds..	75.0	75.0	75.0	4	8	5
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	12.5			
Yield per acre.....bushels..	249.0	250.0	210.0			
Potash (K_2O) per acre.....pounds..	105.0	105.0	105.0	4	8	7
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	17.5			
Yield per acre.....bushels..	254.0	237.0	195.0			

SEC. D.—ON SASSAFRAS LOAM, RIVERHEAD, LONG ISLAND, N. Y.

[Fertilizer application, 1,800 pounds per acre; average control (4-10-0) yield, 185.9 bushels per acre; in cooperation with the Suffolk County Farm Bureau.]

Potash (K_2O) per acre.....pounds..	54.0	54.0	54.0	4	10	3
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	8.85			
Yield per acre.....bushels..	254.8	276.0	244.7			
Potash (K_2O) per acre.....pounds..	90.0	90.0	90.0	4	10	5
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	14.75			
Yield per acre.....bushels..	251.5	259.3	235.8			
Potash (K_2O) per acre.....pounds..	126.0	126.0	126.0	4	10	7
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	20.65			
Yield per acre.....bushels..	235.2	224.4	211.1			

SEC. E.—ON CARIBOU LOAM, PRESQUE ISLE, ME.

[Fertilizer application, 1,800 pounds per acre; average control (5-10-0) yield, 238 bushels per acre; in cooperation with the Maine Agricultural Experiment Station.]

Potash (K_2O) per acre.....pounds..	36.0	36.0	36.0	5	10	2
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	5.9			
Yield per acre.....bushels..	277.0	278.0	300.0			
Potash (K_2O) per acre.....pounds..	72.0	72.0	72.0	5	10	4
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	11.8			
Yield per acre.....bushels..	278.0	295.0	298.0			
Potash (K_2O) per acre.....pounds..	108.0	108.0	108.0	5	10	6
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	17.7			
Yield per acre.....bushels..	307.0	313.0	285.0			
Potash (K_2O) per acre.....pounds..	144.0	144.0	144.0	5	10	8
Borax ($Na_2B_4O_7$) per acre.....do....	None.	None.	23.6			
Yield per acre.....bushels..	290.0	309.0	281.0			

In New Jersey (Table II, sec. C) the story is somewhat similar, although here the yield decreases, as one would expect, with the increase in the potash containing borax, so that with 7 per cent potash goods the yield is 254 bushels with sulphate of potash as compared with 195 bushels with the Searles Lake potash.

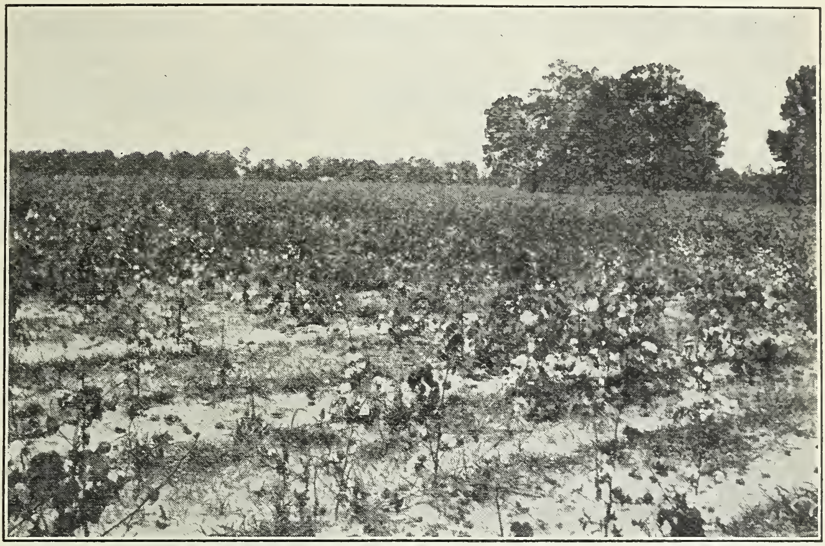


FIG. 16.—The cotton shown in the foreground was fertilized with 800 pounds per acre of 3–8–3 fertilizer and in addition 100 pounds of potash salt carrying 12 pounds of borax. The section of the field seen in the background received only the mixed fertilizer. For a nearer view of this field, see figure 17.

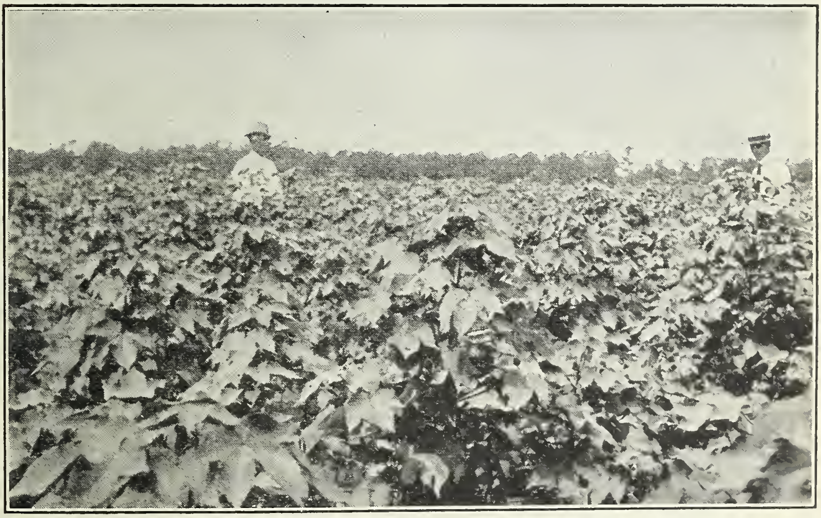


FIG. 17.—A near view of a part of the cotton field shown in figure 16, where only the mixed fertilizer was used without the additional potash salt carrying borax. Figure 16 shows the effect of the potash salt containing borax.

A similar result is shown on Long Island, N. Y., although the difference is not so marked, and with the 3 per cent potash goods practically no decrease in yield was observed. (Table II, sec. D.)

In Maine (Table II, sec. E) the difference also is slight; in fact, a slightly increased yield was noted in the Searles Lake potash, both with the 2 and the 4 per cent goods. It would seem, therefore, that the method of distributing the fertilizer in the experiment, being slightly different from the practice of the farmers, aided no doubt by the weather conditions at the time of planting, contributed toward less harm from borax than was experienced by many of the farmers in that locality. The experiments show that different soil types and climatic factors play a not inappreciable part in determining the toxic limits of such a constituent as borax in fertilizers. They show that even a small application of borax, under unfavorable weather conditions and local concentration in the soil, may produce unfavorable results.

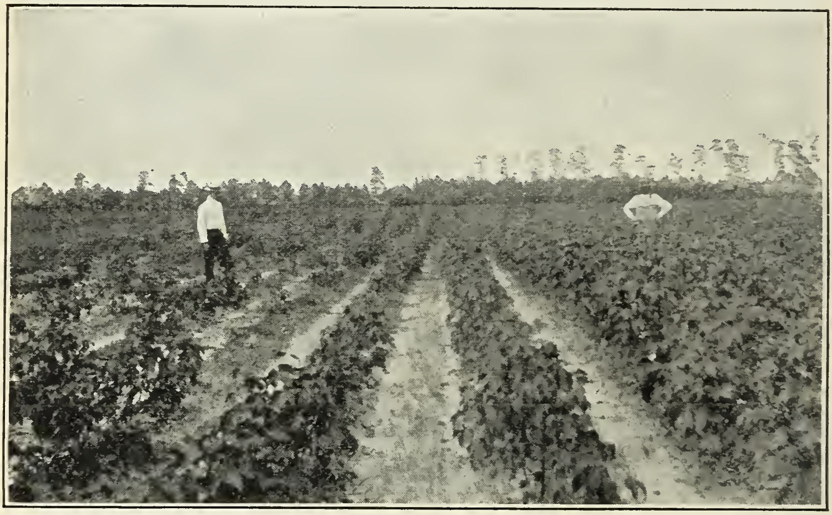


FIG. 18.—The cotton on the right was fertilized with 200 pounds of 3-8-0 fertilizer per acre; that on the left with 200 pounds of 3-8-0 fertilizer and in addition 50 pounds of potash salt containing 8 pounds of borax.

EFFECT OF BORAX IN COTTON FERTILIZERS.

The effect of borax in fertilizers used for cotton was investigated by Dr. Oswald Schreiner and Dr. J. J. Skinner during the latter part of August in the vicinity of Florence and Darlington, S. C., at which places the Office of Soil-Fertility Investigations conducts experiments with fertilizers. Samples of the fertilizers were obtained and later analyzed by Mr. R. B. Deemer, of its laboratory. The accompanying reproductions from photographs show the type of injury to cotton by the Searles Lake potash. (Figs. 16 to 23.)

REPORT ON THE CONDITION OF COTTON FIELDS IN SOUTH CAROLINA.

In the cotton fields of South Carolina Searles Lake potash was applied as an addition to the factory-mixed goods. Below is given a general description of some of the fields inspected on August 27 and 28, 1919.

(1) The soil in this field is a sandy loam and is fairly uniform. It is well drained. The field comprises 18 to 20 acres. A factory-mixed fertilizer analyzing 3 per cent NH_3, 8 per cent P_2O_5, and 3 per cent K_2O was used on the entire field at the rate of 800 pounds per acre. On about 4 acres an additional application of 75 pounds per acre of Searles Lake potash was used. Samples of both of these fertilizers were secured. The Searles Lake potash was found to contain 12.38 per cent of borax and the 3–8–3 fertilizer 1.2 per cent of borax. The cotton fertilized with the 3–8–3 fertilizer was nearly waist high. Where the Searles Lake potash was used the plants were scarcely knee high; some had died when 4 to 5 inches tall. The fruiting was light and the few bolls that had stood were maturing prematurely.

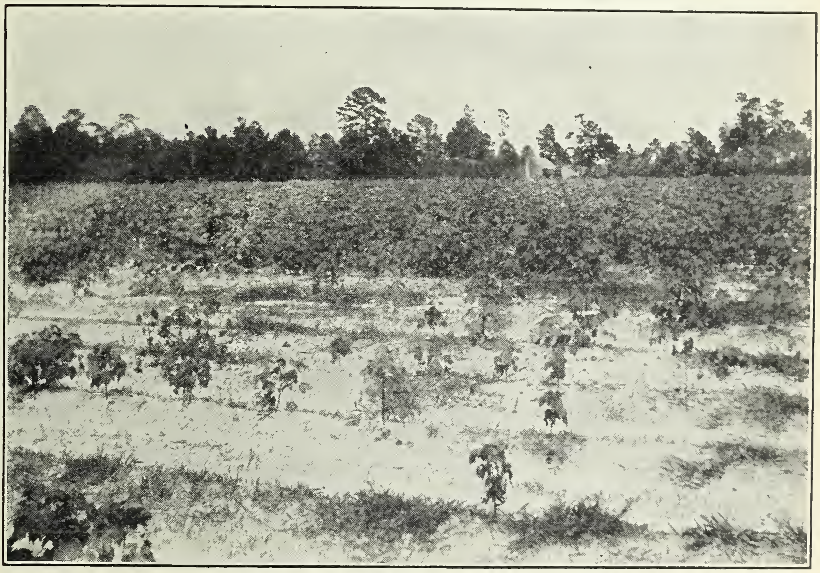


FIG. 19.—The cotton in the foreground was fertilized with 200 pounds of 3–8–0 fertilizer and in addition 50 pounds per acre of potash salt carrying 8 pounds of borax. On that in the background 200 pounds of 3–8–0 fertilizer without additional potash salt was applied.

(2) This field is not so well drained as the first one. The character of the soil is very similar. A 3–8–3 fertilizer was used, and on the west end Searles Lake potash was used in addition at the rate of 100 pounds per acre. This is shown in figures 16 and 17. The cotton where the potash was applied in some areas had died, and where it did survive had made a growth of 6 to 8 inches. The bolls had opened prematurely. This part of the field will yield 70 to 75 per cent less than that part where only the 3–8–3 fertilizer was used. It was estimated that the area where the Searles Lake potash was used would yield 400 to 500 pounds of seed cotton, while the portion of the field where only the mixed fertilizer was used would yield 1,400 to 1,500 pounds per acre.

(3) This field comprised about 15 acres. It was given 800 pounds of 3–8–3 fertilizer and 100 pounds of Searles Lake potash per acre. Corn and peas were grown in 1917 and 1918. An excellent crop is reported to have been made. The cotton crop of 1919 was a failure except in the lower lying areas. A poor stand was secured and a considerable number of the plants died when young. A yield of 200 to 300 pounds of seed cotton per acre will be secured. There was some wilt in the cotton on the farm, which occurred in small areas here and there. This appeared in those parts of the field where no Searles Lake potash was used as well as where it was used. The damage from disease on this farm was small and is not an appreciable factor.

(4) The soil of this field is a heavy sandy loam and rather poorly drained. Searles Lake potash (12 per cent borax) in addition to a no-potash factory-mixed fertilizer was used. The Searles Lake potash was used on all of the cotton in quantities varying from 50 to 150 pounds per acre. The cotton germinated poorly and was replanted. A considerable number of the plants died when young. The crop on this field, about 70 acres, was a failure. The field presented an uneven appearance; the foliage was badly rusted, the plants poorly fruited, and the bolls matured undeveloped.

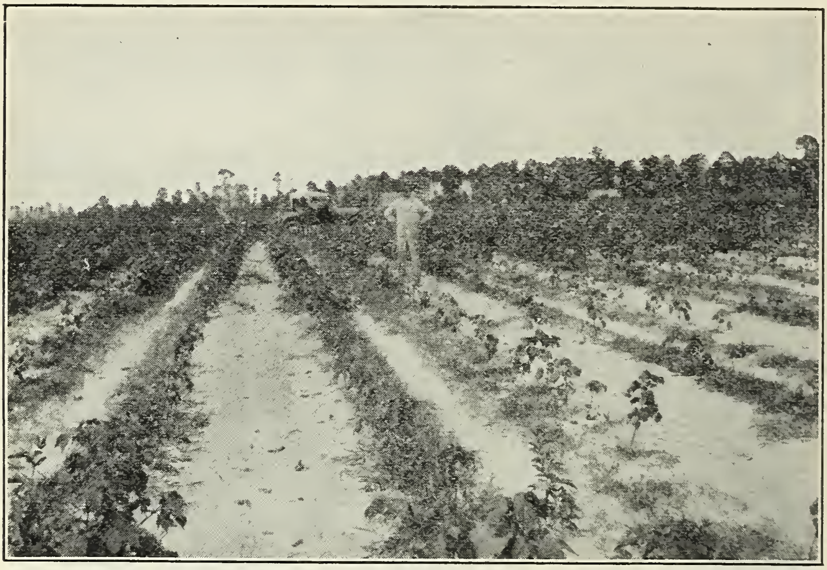


FIG. 20.—Cotton field fertilized with 200 pounds per acre of a 4–6–0 fertilizer and in addition 100 pounds of potash salt carrying 16 pounds of borax. (See fig. 21.)

(5) This farm is located in the southern part of Darlington County. Searles Lake potash containing 16 per cent of borax was used on part of this cotton, in addition to a 3–8–0 fertilizer. There had been used 200 pounds per acre of a 3–8–0 fertilizer and 50 pounds of Searles Lake potash. In one of the fields where the Searles Lake potash was used the crop, with the exception of a few straggling stalks, had died out. In another part of the same field where only the 3–8–0 goods were used the cotton was 4 to 5 feet high and well fruited. This field is shown in figure 18. In figure 19 is shown another cotton field on the same farm, a section of which was fertilized with Searles Lake salts. The soil in this section is somewhat heavier than in the section where the farms mentioned above are located. In this part of the county smaller quantities of fertilizers are used than elsewhere.

(6) Cotton on a farm near the one just described was also examined. The soil conditions were very similar to those on the above place. The topography is flat and the drainage is by means of open ditches. There were several hundred acres of cot-

ton on this farm, about two-thirds of which had been fertilized with Searles Lake potash containing 16 per cent of borax. There had been used as a general fertilizer 200 to 400 pounds per acre of a 4–6–0 mixture. The Searles Lake potash was used at the rate of approximately 100 pounds per acre. All of the fertilizing materials were applied as a side dressing after the cotton was up. The condition of this crop on August 27, 1919, and the character of injury apparently caused by the Searles Lake potash are shown in figures 20 and 21 and figures 22 and 23.

REPORT ON FIELD EXPERIMENTS WITH COTTON FERTILIZERS CONTAINING BORAX.

The tests with fertilizers containing borax were carried out cooperatively, under the supervision of Dr. J. J. Skinner, on cotton farms located on six different soil types in Georgia, South Carolina, and North Carolina. The potash used in the fertilizer mixtures was obtained from several American sources, sulphate of potash prepared from Utah alunite, Nebraska Lake potash, and Searles Lake potash, the latter containing 6.25 per cent of borax ($Na_2B_4O_7$). The results with cotton at these various places, presented in tabular form, giving the yields obtained with sulphate of potash, Nebraska potash, and Searles Lake potash, are reported herewith. Table III gives in pounds the quantities of potash applied per acre and of borax applied along with the potash in each experiment. The composition of the fertilizer used is stated in the last three columns of the table. In all these experiments the potash was added in amounts to give 2, 4, 6 and 8 per cent of this ingredient in the fertilizer mixtures, but the percentage of phosphate and ammonia differed in the different places, according to the needs and practice of the region. The average yield of cotton without potash in the

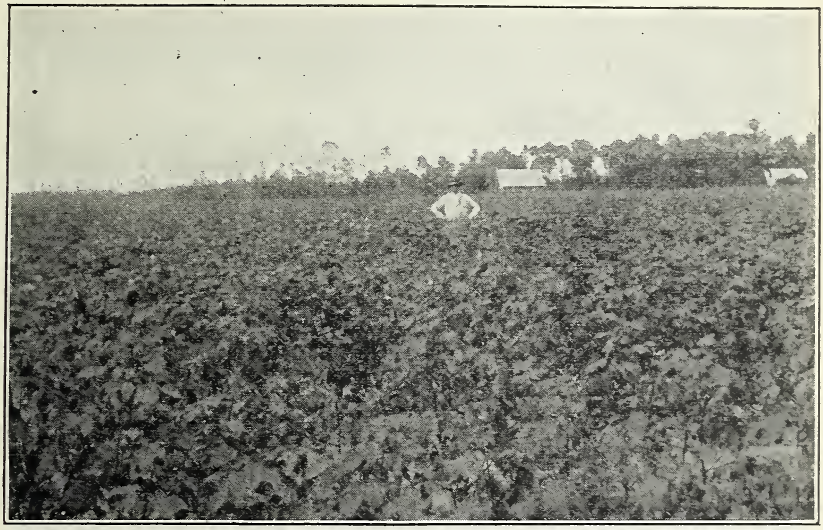


FIG. 21.—Cotton field fertilized with 200 pounds of 4–6–0 fertilizer without additional potash salt. (See fig. 20.)

fertilizer, as determined in these experiments, is stated at the head of each section of the table for comparison.

An examination of Table III will show that at all these places the yield of cotton has responded to the potash in the fertilizers, but when borax was also present in certain amounts this interfered materially with the yields.

On the Cecil sandy loam at Athens, Ga. (Table III, sec. A), Searles Lake potash, with approximately 2 pounds of borax per acre, proved to be slightly better than Nebraska potash and sulphate of potash, but as the quantity increased to approximately 4, 6, and 8 pounds of borax per acre the yield decreased accordingly, so that with 8 pounds of borax approximately 300 pounds less of cotton per acre was obtained than with the potash from other sources. The plants subjected to the influences of borax also showed the characteristic symptoms of injury in what might be termed the milder form, as distinguished from the severe injury with larger amounts of borax, which prevented germination and caused the death of the young plants. This injury is well illustrated by the notes from Dr. Skinner's notebook on the conditions in this field as observed by him on July 24, 1919, as follows:

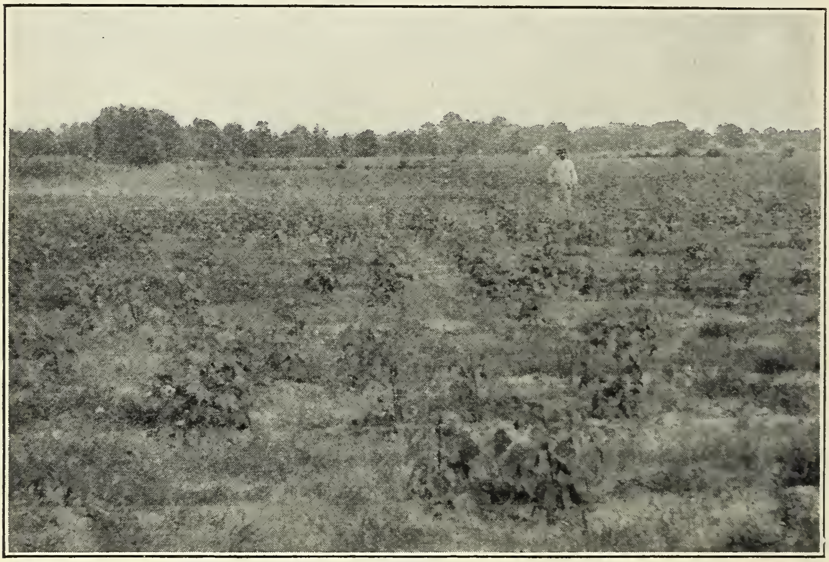


FIG. 22.—An abandoned cotton field, not considered profitable enough to pay for continuing cultivation. It was fertilized with 400 pounds per acre of 4-6-0 fertilizer and in addition 100 pounds of potash salt carrying 16 pounds of borax. The fertilizers were applied as a side dressing.

> The sulphate of potash is the best of the series, followed by the Nebraska Lake potash, the Searles Lake potash being the poorest. The 2 per cent potash of the Searles Lake salt is not altogether as good as the 2 per cent goods of the other potash materials. The growth and condition of the plants decrease as the potash increases.

The 8 per cent goods is poor, has made less growth, about 25 to 30 per cent less than the 8 per cent potash goods of the sulphate series. The foliage is of a lighter color, having lost the dark-green healthy color which is characteristic of the plants given the other potash treatments in the experiment. This light-green foliage, found most strikingly in the 8 per cent goods, is apparent in the 6 per cent goods and also slightly in the 4 per cent goods, but not in the 2 per cent goods; here the only apparent difference is the slight decrease in growth as compared with the 2 per cent goods of the other potash materials.

On the Norfolk fine sandy loam at Florence, S. C. (Table III, sec. B), the potash salt carrying with it 3 pounds of borax per acre gave a lower yield per acre, approximately 250 to 300 pounds, than the other potash salts, and this was even slightly less than the no-potash fertilizer. This same relationship holds true for the other higher amounts of borax.

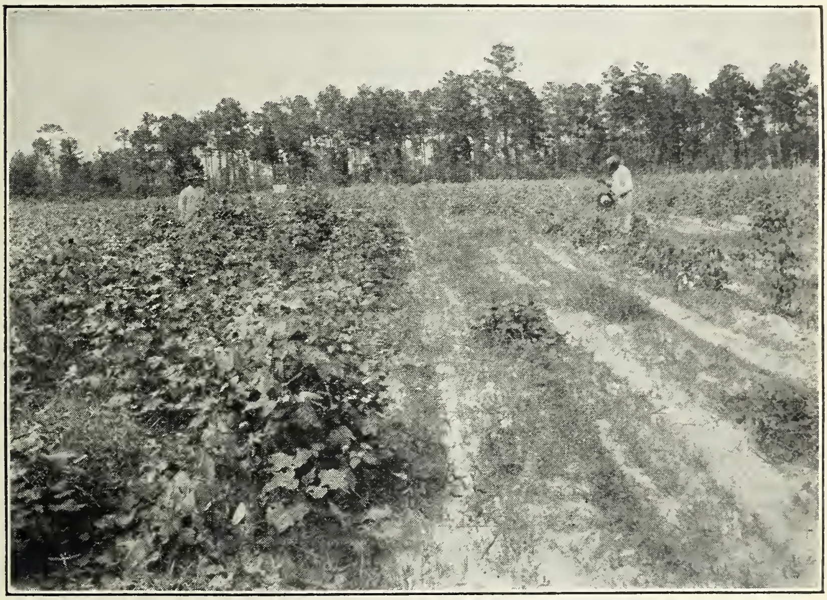


FIG. 23.—Field of cotton on the left fertilized with 400 pounds of 4–6–0 fertilizer per acre. The cotton on the right was fertilized with 400 pounds of 4–6–0 fertilizer per acre and in addition 100 pounds of potash salt carrying 16 pounds of borax.

On the Norfolk coarse sandy loam in Darlington County, S. C. (Table III, sec. C), this effect of borax on the yield is not so marked, the lesser quantity of about 3 pounds per acre, in fact, showing an increase over the other fertilizers. This is exceptional, however, and not maintained as the 4, 6, and 8 per cent potash goods are compared. The borax-containing potash salt causes a successive decrease in yield as the amount applied is increased, while with the other salts the reverse is true. Some other fertility factors enter into the case on this soil, which it is not necessary to discuss here, but the results show, nevertheless, the influence of the presence of borax on the yield of cotton.

TABLE III.—*Yields of seed cotton grown on different soil types treated with fertilizers of stated composition, from several sources, applied at given rates per acre and containing varying percentages of borax; tests of 1919.*

SEC. A.—ON CECIL SANDY LOAM, ATHENS, GA.

[Fertilizer application, 600 pounds per acre; variety grown, College No. 1; average control (3-10-0) yield, 1,560 pounds per acre; in cooperation with the Georgia State College of Agriculture.]

Items of comparison.	Sulphate of potash.	Nebraska potash.	Searles Lake potash.	Composition of fertilizer (per cent).		
				NH_3.	P_2O_5.	K_2O.
Potash (K_2O) per acre.................pounds..	12	12	12	3	10	2
Borax ($Na_2B_4O_7$).............................do....	None.	None.	1.97			
Yield per acre.................................do....	1,708	1,732	1,736			
Potash (K_2O) per acre.....................do....	24	24	24	3	10	4
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	3.94			
Yield per acre.................................do....	1,732	1,662	1,582			
Potash (K_2O) per acre.....................do....	36	36	36	3	10	6
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	5.9			
Yield per acre.................................do....	1,732	1,756	1,468			
Potash (K_2O) per acre.....................do....	48	48	48	3	10	8
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	7.87			
Yield per acre.................................do....	1,664	1,672	1,362			

SEC. B.—ON NORFOLK FINE SANDY LOAM, FLORENCE, S. C.

[Fertilizer application, 900 pounds per acre; variety grown, Dixie (wilt resistant); average control (3-8-0) yield, 1,862 pounds per acre; in cooperation with the South Carolina Agricultural Experiment Station.]

Potash (K_2O) per acre.................pounds..	18	18	18	3	8	2
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	2.95			
Yield per acre.................................do....	2,108	1,990	1,824			
Potash (K_2O) per acre.....................do....	36	36	36	3	8	4
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	5.9			
Yield per acre.................................do....	2,136	1,936	1,856			
Potash (K_2O) per acre.....................do....	54	54	54	3	8	6
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	8.85			
Yield per acre.................................do....	2,152	1,946	1,790			
Potash (K_2O) per acre.....................do....	72	72	72	3	8	8
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	11.8			
Yield per acre.................................do....	2,080	1,974	1,714			

SEC. C.—ON NORFOLK COARSE SANDY LOAM, DARLINGTON COUNTY, S. C.

[Fertilizer application, 900 pounds per acre; variety grown, Toole; average control (3-8-0) yield, 902 pounds per acre; in cooperation with the South Carolina Agricultural Experiment Station.]

Potash (K_2O) per acre.................pounds..	18	18	18	3	8	2
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	2.95			
Yield per acre.................................do....	1,104	1,076	1,174			
Potash (K_2O) per acre.....................do....	36	36	36	3	8	4
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	5.90			
Yield per acre.................................do....	1,132	1,216	1,106			
Potash (K_2O) per acre.....................do....	54	54	54	3	8	6
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	8.85			
Yield per acre.................................do....	1,142	1,308	1,068			
Potash (K_2O) per acre.....................do....	72	72	72	3	8	8
Borax ($Na_2B_4O_7$) per acre.................do....	None.	None.	11.8			
Yield per acre.................................do....	1,144	1,302	1,006			

TABLE III.—*Yields of seed cotton grown on different soil types treated with fertilizers of stated composition, from several sources, applied at given rates per acre and containing varying percentages of borax; tests of 1919*—Continued.

SEC. D.—ON PORTSMOUTH SANDY LOAM, DARLINGTON COUNTY, S. C.

[Fertilizer application, 900 pounds per acre; variety grown, Hartsville No. 12; average control (3-8-0) yield, 584 pounds per acre; in cooperation with the South Carolina Agricultural Experiment Station.]

Items of comparison.	Sulphate of potash.	Nebraska potash.	Searles Lake potash.	Composition of fertilizer (per cent).		
				NH_3.	P_2O_5.	K_2O.
Potash (K_2O) per acre..................pounds..	18	18	18	3	8	2
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	2.95			
Yield per acre..............................do....	792	748	814			
Potash (K_2O) per acre......................do....	36	36	36	3	8	4
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	5.9			
Yield per acre..............................do....	784	768	714			
Potash (K_2O) per acre......................do....	54	54	54	3	8	6
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	8.85			
Yield per acre..............................do....	770	758	678			
Potash (K_2O) per acre......................do....	72	72	72	3	8	8
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	11.8			
Yield per acre..............................do....	750	726	574			

SEC. E.—ON NORFOLK VERY FINE SANDY LOAM, FLORENCE, S. C.

[Fertilizer application, 900 pounds per acre; variety grown, Dixie (wilt resistant); average control (3-8-0) yield, 1,698 pounds per acre; in cooperation with the Peedee Experiment Station.]

Potash (K_2O) per acre..................pounds..	18	18	18	3	8	2
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	2.95			
Yield per acre..............................do....	2,178	1,666	1,730			
Potash (K_2O) per acre......................do....	36	36	36	3	8	4
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	5 9			
Yield per acre..............................do....	2,004	1,600	1,662			
Potash (K_2O) per acre......................do....	54	54	54	3	8	6
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	8.85			
Yield per acre..............................do....	1,960	1,760	1,702			
Potash (K_2O) per acre......................do....	72	72	72	3	8	8
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	11.80			
Yield per acre..............................do....	1,838	1,838	1,458			

SEC. F.—ON DUNBAR SANDY LOAM, NEW BERN, N. C.

[Fertilizer application, 900 pounds per acre; average control (5-7-0) yield, 1,764 pounds per acre; in cooperation with the North Carolina Agricultural Experiment Station.]

Potash (K_2O) per acre..................pounds..	18	18	18	5	7	2
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	2 95			
Yield per acre..............................do....	1,940	1,986	1,612			
Potash (K_2O) per acre......................do....	36	36	36	5	7	4
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	5.90			
Yield per acre..............................do....	1,888	1,934	1,518			
Potash (K_2O) per acre......................do....	54	54	54	5	7	6
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	8.85			
Yield per acre..............................do....	1,988	1,904	1,498			
Potash (K_2O) per acre......................do....	72	72	72	5	7	8
Borax ($Na_2B_4O_7$) per acre..................do....	None.	None.	11.80			
Yield per acre..............................do....	2,200	1,970	1,564			

On the Portsmouth sandy loam, near Darlington, S. C. (Table III, sec. D), the effect of borax is very similar to that on the Norfolk coarse sandy loam described above, in that 3 pounds of borax per acre gave a slight increase in yield over the potash from other sources, which was not maintained as the borax rose to 6, 9, and 12 pounds per acre in the 4, 6, and 8 per cent potash fertilizers. A progressive decrease in yield will be noted, with only 574 pounds with the higher amount of borax, as compared with 726 for the Nebraska potash and 750 pounds for the sulphate of potash. This also was a poor field, in the consideration of which other fertilizer and soil questions enter, but these need not be presented here. The results show unmistakably the influence of borax on the yield.

On the Norfolk very fine sandy loam, at the Peedee Experiment Station, (Table III, sec. E), the borax-containing potash salt compares very favorably with the Nebraska potash salts in the 2 and 4 per cent potash fertilizers, but both fall very materially behind the sulphate of potash. In fact, these two low results with Nebraska potash would seem to be due to other causes, since they fall even below the no-potash goods. This relationship between Nebraska potash and Searles Lake potash was, however, not maintained as the amount of potash, and consequently the amount of borax, was increased. With an increase in borax the yield of cotton progressively decreases, and with 12 pounds of borax per acre the yield with the borax-containing potash salt falls nearly 400 pounds of cotton below that obtained with fertilizers containing potash from other sources.

On the Dunbar sandy loam at New Bern, N. C. (Table III, sec. F) the Searles Lake potash-salt yield is less than the no-potash control, even in the 2 per cent fertilizer, and with the 4, 6, and 8 per cent potash fertilizer it is slightly lower and in all cases much below the other salts.

GREENHOUSE EXPERIMENTS IN POTS ON THE TOXICITY OF BORAX.

In addition to the field experiments with potatoes and with cotton presented in the foregoing pages, some experiments were conducted in the greenhouse, in which a direct effort was made to determine whether such small amounts of borax as Conner suggested in his original communication could produce such markedly toxic effects. This work was carried out by Dr. J. J. Skinner and Mr. F. R. Reid. An experiment was made in pots, using wheat as the indicator of toxicity. Some 12 fertilizer mixtures were prepared, which contained in stages from 0.1 up to 3 per cent of borax, and each of these fertilizers was then used in quantities ranging from 100 to 1,000 pounds per acre. Wheat seedlings, which are well suited for such tests, were used to indicate the tolerance for borax, by counting the leaf tips that were bleached after three or four weeks' growth in these various fertilizer mixtures. The results of this experiment are presented on the accompanying diagram (fig. 24), in which the vertical axis represents the percentage content of borax in the fertilizer used and the horizontal axis the amount of fertilizer in pounds per acre. The numbers indicate the leaves affected by the characteristic borax reaction. There is also a line drawn through this diagram, which shows 2½ pounds of borax per acre. It will be noted that on one side of this line the number of leaves of wheat affected is very large, and that on the other side of the line they are practically zero or very low. Some of the latter, no doubt, would have to be ascribed to the high concentration of fertilizer salts rather than specifically to borax. From this experiment it would seem that very small quantities of borax can cause injury to wheat plants, for 2½ pounds of borax per acre is an exceedingly small amount, especially when

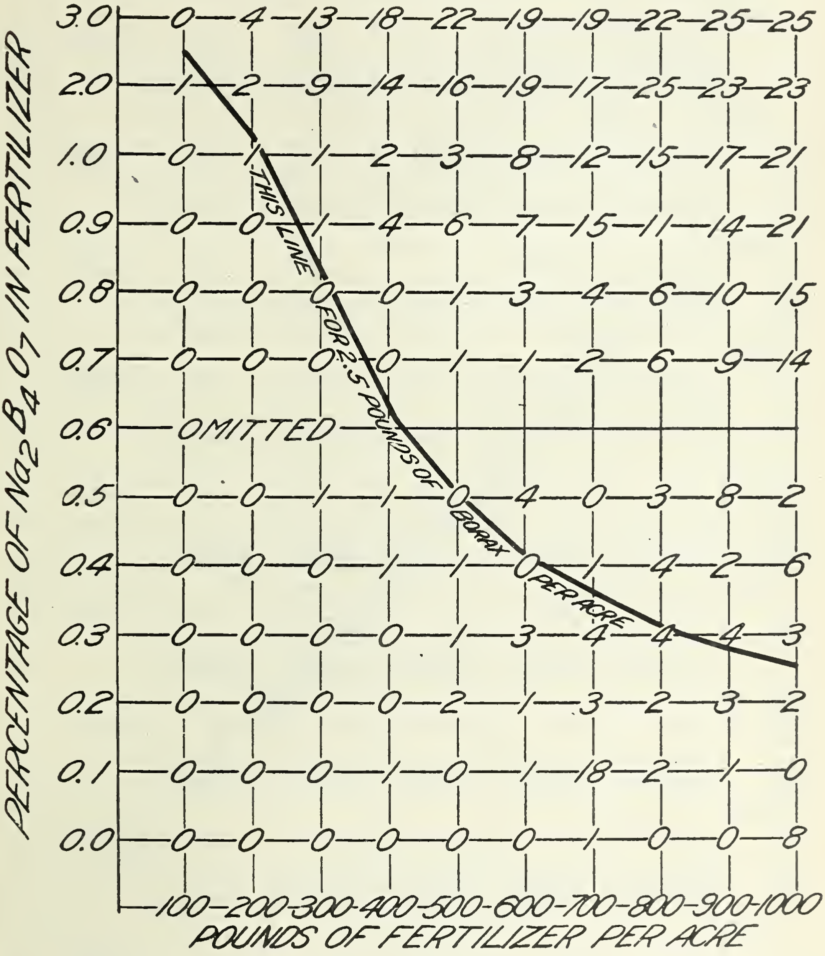
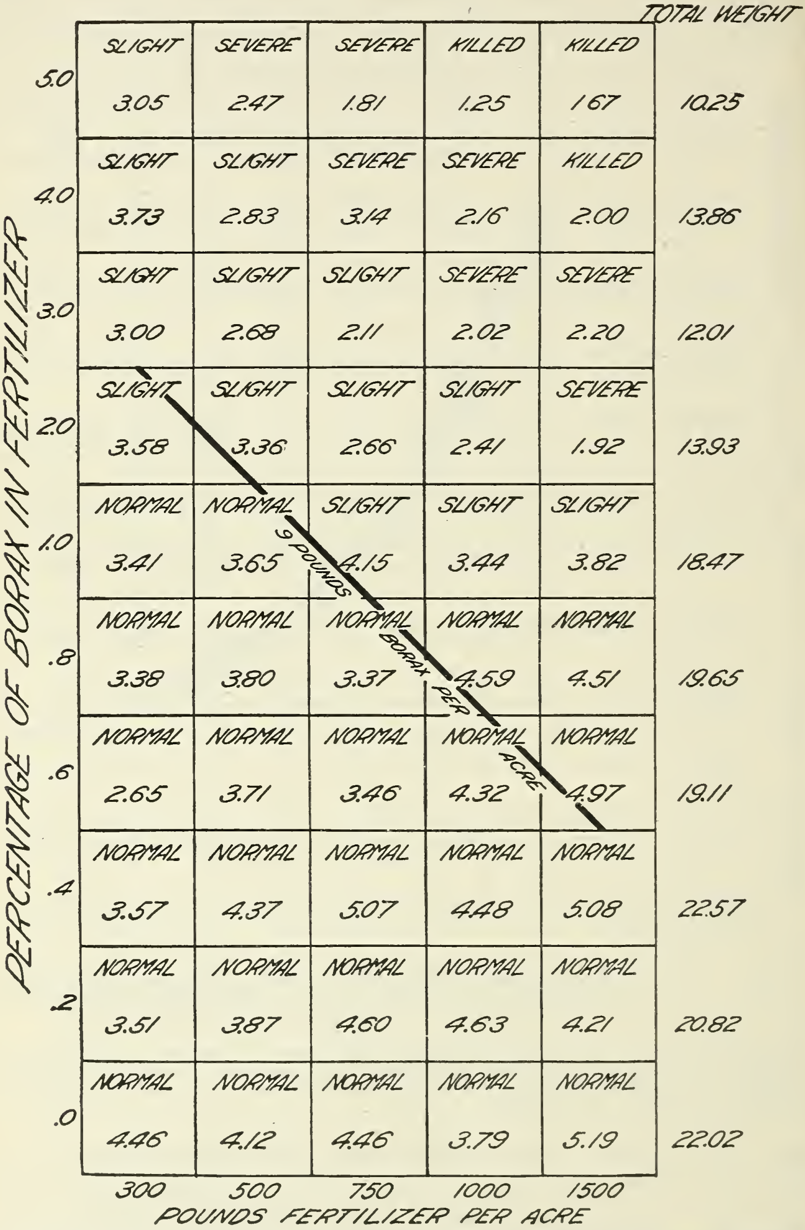


FIG. 24.—Number of leaf tips (wheat) which show the effect of borax. The count was made on those leaves the tips of which showed bleaching followed by complete breaking down of the cell structure, which was indicated by a complete drying of the tip. Reading made January 8, 1919. Planted December 11, 1918, 25 wheat seedlings being grown in each set.

considered in comparison with other so-called plant poisons, such as copper sulphate or even mercury salts, which can be added to



PERCENTAGE OF BORAX IN FERTILIZER	300	500	750	1000	1500	TOTAL WEIGHT
5.0	SLIGHT 3.05	SEVERE 2.47	SEVERE 1.81	KILLED 1.25	KILLED 1.67	10.25
4.0	SLIGHT 3.73	SLIGHT 2.83	SEVERE 3.14	SEVERE 2.16	KILLED 2.00	13.86
3.0	SLIGHT 3.00	SLIGHT 2.68	SLIGHT 2.11	SEVERE 2.02	SEVERE 2.20	12.01
2.0	SLIGHT 3.58	SLIGHT 3.36	SLIGHT 2.66	SLIGHT 2.41	SEVERE 1.92	13.93
1.0	NORMAL 3.41	NORMAL 3.65	SLIGHT 4.15	SLIGHT 3.44	SLIGHT 3.82	18.47
.8	NORMAL 3.38	NORMAL 3.80	NORMAL 3.37	NORMAL 4.59	NORMAL 4.51	19.65
.6	NORMAL 2.65	NORMAL 3.71	NORMAL 3.46	NORMAL 4.32	NORMAL 4.97	19.11
.4	NORMAL 3.57	NORMAL 4.37	NORMAL 5.07	NORMAL 4.48	NORMAL 5.08	22.57
.2	NORMAL 3.51	NORMAL 3.87	NORMAL 4.60	NORMAL 4.63	NORMAL 4.21	20.82
.0	NORMAL 4.46	NORMAL 4.12	NORMAL 4.46	NORMAL 3.79	NORMAL 5.19	22.02

FIG. 25.—Injury to cotton seedlings grown on Norfolk sandy loam with fertilizers of different borax content. The green weight of the seedling plants is stated in grams. Duration of experiment, 60 days.

soils in amounts of 50 pounds per acre without any appreciable effect other than stimulation to indicate toxicity. Borax seems, therefore, to have a very decided toxic action, even when present in small amounts, which makes the question of deciding what limit to allow in fertilizers an extremely important one.

A similar experiment was subsequently made with cotton seedlings as indicators of toxicity. The fertilizer mixtures contained from 0.2 up to 5 per cent of borax, and each fertilizer was applied at rates from 300 to 1,500 pounds. The results of this experiment are briefly presented on the accompanying diagram (fig. 25), in which the words "slight," "severe," and "killed" indicate the degree of injury sustained. A line is drawn through the diagram which approximately indicates the 9-pound per acre borax limit, above which practically all plants are showing borax injury and below which the plants appear to be normal. The field results already presented show, of course, that even smaller amounts of borax per acre will affect the yield of cotton. There is also presented in the diagram the green weights of the plants in the various fertilizer mixtures. Outside of the diagram, on the right, is given the total green weight of the plants in the five pots which had received fertilizers with the same percentage of borax but different amounts of the fertilizers. These figures are directly comparable in so far as the effect of the borax is concerned. It will be noted that the no-borax series, at the bottom, showed a total weight of 22.02 grams, whereas the 5 per cent borax series, at the top, showed a total weight of only 10.25 grams, with a fairly uniform decrease in green weight as the borax content in the fertilizer increased.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY
△